BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 12069

SUBJECT: Effects of Including Uprange and Right Redesignation Capability on Landing the Lunar Module in a Circular Target Area - Case 310

DATE: December 22, 1969

FROM: K. P. Klaasen

ABSTRACT

The landing point designator (LPD) redesignation delta-V required to land the LM in a circular target area with a given probability of success can be reduced significantly if right and/or uprange redesignation capability is included along with the generally accepted left and downrange capability. For the case of a 99% probability of landing in a circle of radius 3000 ft. given a 1σ automatic landing error circle of radius 2500 ft., a redesignation delta-V budget of 250 fps is required if only left and downrange redesignations are permitted, but only 135 fps is required if right and uprange capability is included. In addition, the navigation accuracy is shown to be a major factor in determining the redesignation delta-V requirement. A decrease in landing site uncertainty from σ = 2500 ft. to σ = 1640 ft. decreases the required delta-V budget from 135 fps to 0 fps in the case mentioned above.

Uprange and right redesignation capability using the LPD is restricted by structural viewing limitations through the LM window. However, at an altitude of 5000 ft., it is possible to redesignate up to about 4000 ft. uprange and 10° to the right of the originally designated landing site without violating the landing site visibility constaint. For the case in which uprange or right capability is included, the area from which the target is accessible through redesignation becomes more rectangular in shape. Thus, in order to maximize the probability of making a successful redesignation to the target, the initial aim point should be located near the center of this redesignation capability footprint.

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MEMORANDUM FOR FILE

INTRODUCTION

The probability of landing the lunar module (LM) in a circular target area using the landing point designator (LPD) is directly dependent upon the landing area accessible through redesignation. In several previous studies it has been assumed that, due to landing site visibility requirements, redesignations only to the left or downrange of the designated landing site should be made and that redesignation capability in these directions is limited only by the redesignation delta-V budget and the altitude at which the redesignation is made. Subsequent data on the behavior of the LM while making a redesignation using the LPD show these constraints to be somewhat more limiting than is necessary. The assumption of a set of more realistic constraints affects the proper positioning of the initial aim point and the probability of landing in a given target area. The probabilities calculated under these new sets of constraints were used in the preparation of a Bellcomm presentation on site-dependent LM payload estimates at MSC on October 8, 1969.

ASSUMPTIONS

It is assumed that:

(1) Redesignation capability in distance is based on the Apollo 12 LM descent trajectory and is given in Figures 1a and b. (Data from Reference 1.)

(2) The trajectory below hi-gate is nominal. Deviations of the designated landing point from the initial aim point are due to guidance and navigation errors prior to hi-gate.

RATIONALE FOR NEW CONSTRAINTS

The view out of the LM left-hand window is depicted in Figure 2. The LM Primary Guidance, Navigation, and Control System (PGNCS) automatically maintains the LM attitude so that the current landing site is aligned with the vertical scale on the window. The downrange position of the current site is designated by the window elevation angle which is displayed on the LM onboard computer Display and Keyboard (DSKY).

It is clear that a large portion of the lunar surface to the right of the designated site is not visible due to structural viewing limitations. However, the surface is visible up to a maximum of from 2° to 11° to the right of the designated site when viewed from the reference eye position. A plot of the elevation angle of the landing site on the LPD scale as a function of altitude, presented in Figure 3, shows that, during the portion of the visibility phase between 5000 ft. and 1000 ft. altitude when redesignations would normally be made, the elevation angle is between 40° and 46°. During this period the area about 7° directly to the right of the designated site is visible. The commander can increase the area visible to the right by moving his eye position closer to the window and to the left. For this analysis, a limit of 10° of visibility to the right was chosen. The window edge was assumed to be vertical to simplify the calculations. At an altitude of 5000 ft., the distance visible to the right of the designated site is about 3000 ft. Since the crossrange redesignation capability for 60 fps redesignation delta-V budget is only about 4400 ft. at this altitude, an increased redesignation capability of 3000 ft. to the right is very significant.

Redesignations short of the designated site actually reduce the delta-V required. The lunar surface uprange of the designated site is visible to some degree during almost all of the visibility phase; however, uprange redesignation capability is limited by a loss of visibility due to the fact that the LM pitches up during a short redesignation and the desired landing site may disappear below the bottom of the window. Current estimates indicate that redesignations up to about 4000 ft. uprange can be made at an altitude of 5000 ft. without loss of landing site visibility.

Crossrange redesignations cause the LM to increase its roll angle. Under certain circumstances, a roll angle larger than about 30° could cause landing radar errors as well as crew discomfort. No hard data are available on precisely what the roll angle limitation should be; a 30° roll angle is generally taken to be a practical limit and this was chosen as the limiting factor for LPD crossrange redesignations to the left.

The LPD redesignation capability footprint at 5000 ft. altitude assuming these new constraints is shown in Figure 4 for various redesignation delta-V budgets.

RESULTING OPTIMUM AIMPOINTS AND PROBABILITIES

The optimum initial aim point and the probability of landing in the target area using the LPD were calculated for several circular LM landing error ellipses and target area radii using the procedure of Reference 2. These calculations were done for the cases of: (1) left and downrange redesignation capability only, (2) left, downrange, and uprange capability, and (3) left, downrange, uprange, and right capability. A single redesignation made at 5000 ft. altitude without LPD error was assumed. Figures 5a and b show the redesignation delta-V budget required to land in a circle of radius Δ with 95% and 99% probability of success for 1σ automatic landing error circles of radius 1640 ft. and 2500 ft. It can be seen that the addition of uprange and right redesignation capability greatly reduces the redesignation delta-V required to land in a given target area. Allowing redesignation to the right is an especially effective means of reducing the delta-V requirement in those cases where this requirement is relatively high because, as shown in Figure 4, a given increase in the delta-V budget becomes a much more effective means of increasing the accessible landing area if right capability is included than if only left capability is available.

Figures 5a and b also show that a major factor in determining the redesignation delta-V requirement is the navigation accuracy. For the case of a 99% probability of landing in a circle of radius 3000 ft., an increase in landing site uncertainty from the case of σ = 1640 ft. to σ = 2500 ft. increases the required delta-V budget from 0 fps to 135 fps when both right and uprange capability are included.

The optimum initial aim point locations are shown in Figures 6a, b and c for each of three redesignation capability assumptions. When uprange or right capability is included, the redesignation capability footprint shown in Figure 4 becomes more rectangular in shape. The initial aim point, with coordinates (μ_x, μ_y), should then be located near the center of this area, that is,

$$\mu_x \approx 1/2 \text{ [(left capability)-(right capability)]}$$

and

$$\mu_y \approx 1/2 \text{ [(downrange capability)-(uprange capability)]}$$

where redesignation capability refers to those directions directly downrange or crossrange of the designated site. Positive μ_x indicates to the right and positive μ_y indicates uprange of the center of the target area.

CONCLUSIONS

Right and uprange redesignations can be made to a significant degree without violating the landing site visibility constraint. Crossrange redesignations are limited by a maximum roll angle beyond which landing radar errors and/or crew discomfort result. Assuming a redesignation capability of 10° to the right and 4000 ft. uprange at an altitude of 5000 ft. and a maximum roll angle of 30°, the redesignation delta-V required to land in a circular target area with a given probability of success is significantly less than if only left and downrange redesignations are permitted. For example, a 99% probability of landing in a circle of radius 3000 ft. given an automatic landing error circle of radius 2500 ft. requires about 250 fps of redesignation delta-V if only left and downrange redesignations are permitted but only requires 135 fps if right and uprange capability is also included. With the addition of uprange and right redesignation capability, the initial aim point should be biased approximately a distance of

1/2 [(left capability)-(right capability)]

to the right and

1/2 [downrange capability)-(uprange capability)]

uprange of the center of the desired target area in order to maximize the probability of landing in that area using the LPD.

K.P. Klaasen

2013-KPK-srb

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Attachments:
References
Figures

REFERENCES

1. Hoekstra, T. B., Bellcomm Working Papers, October, 1969.

2. Klaasen, K. P., "Use of Landing Point Designator to Land the Lunar Module in a Circular Target Area", Case 310, Bellcomm Memorandum for File, B69 09039, September 16, 1969.

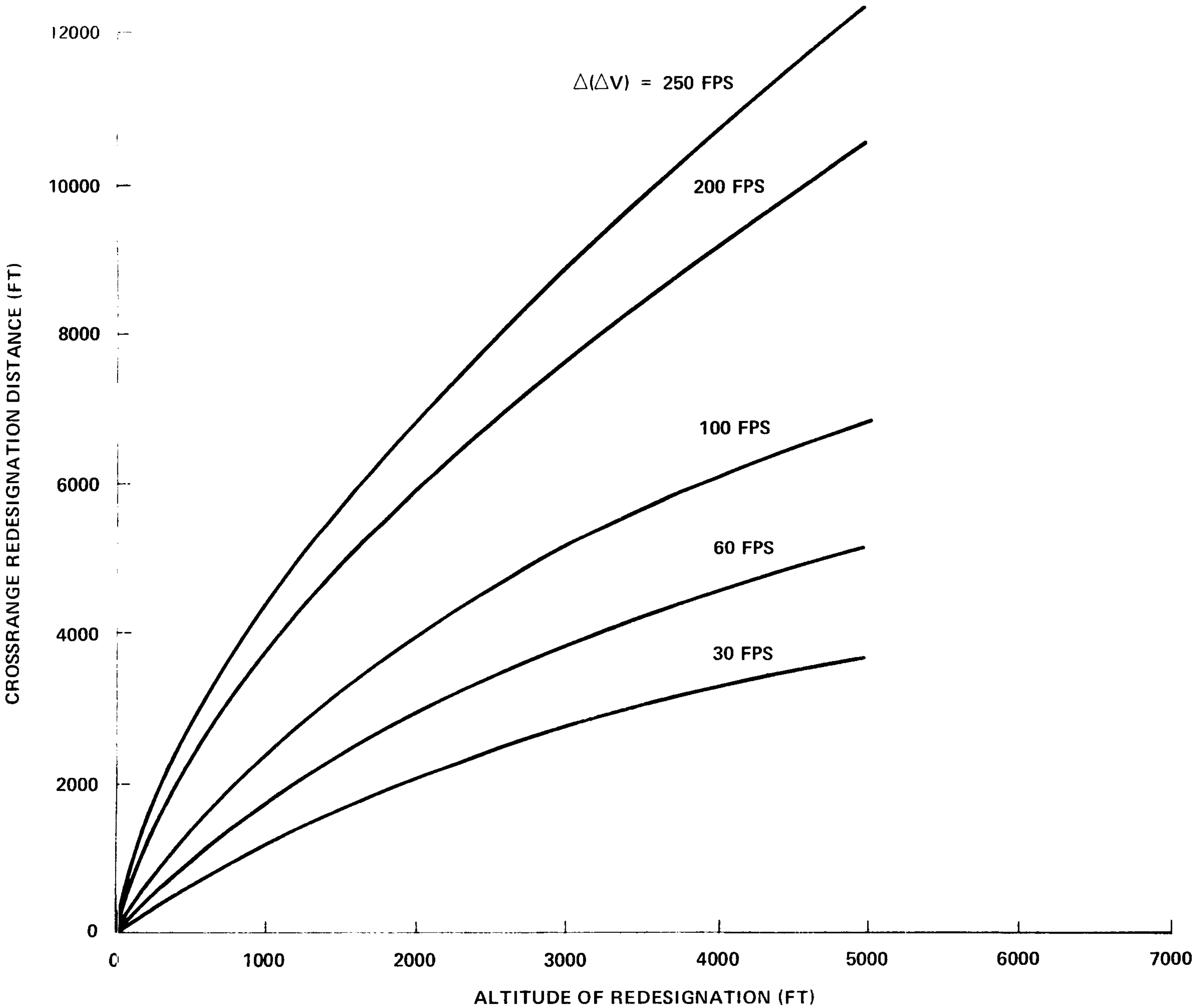

FIGURE 1A – APOLLO 12 CROSSRANGE REDESIGNATION CAPABILITY

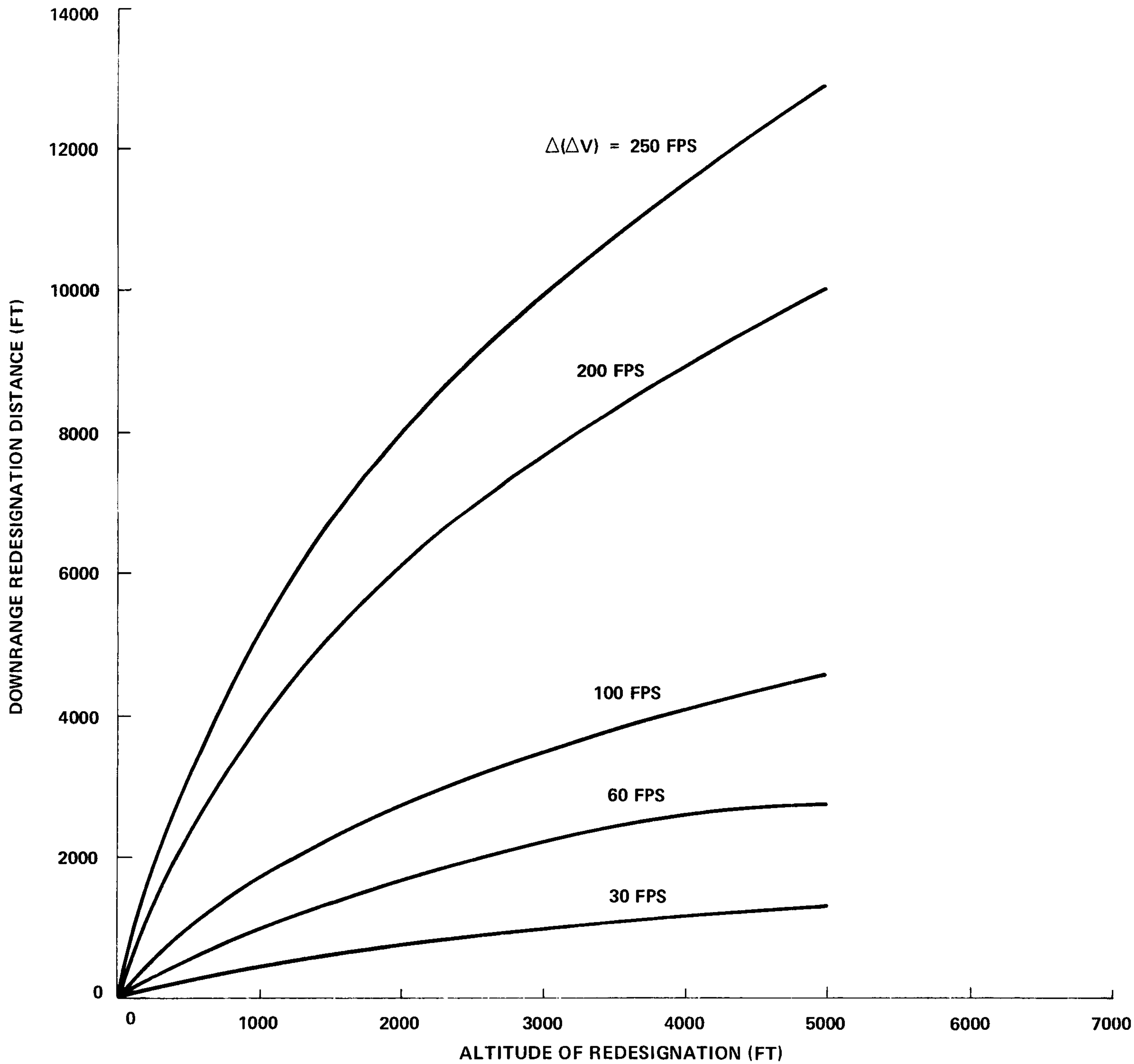

FIGURE 1B – APOLLO 12 DOWNRANGE REDESIGNATION CAPABILITY

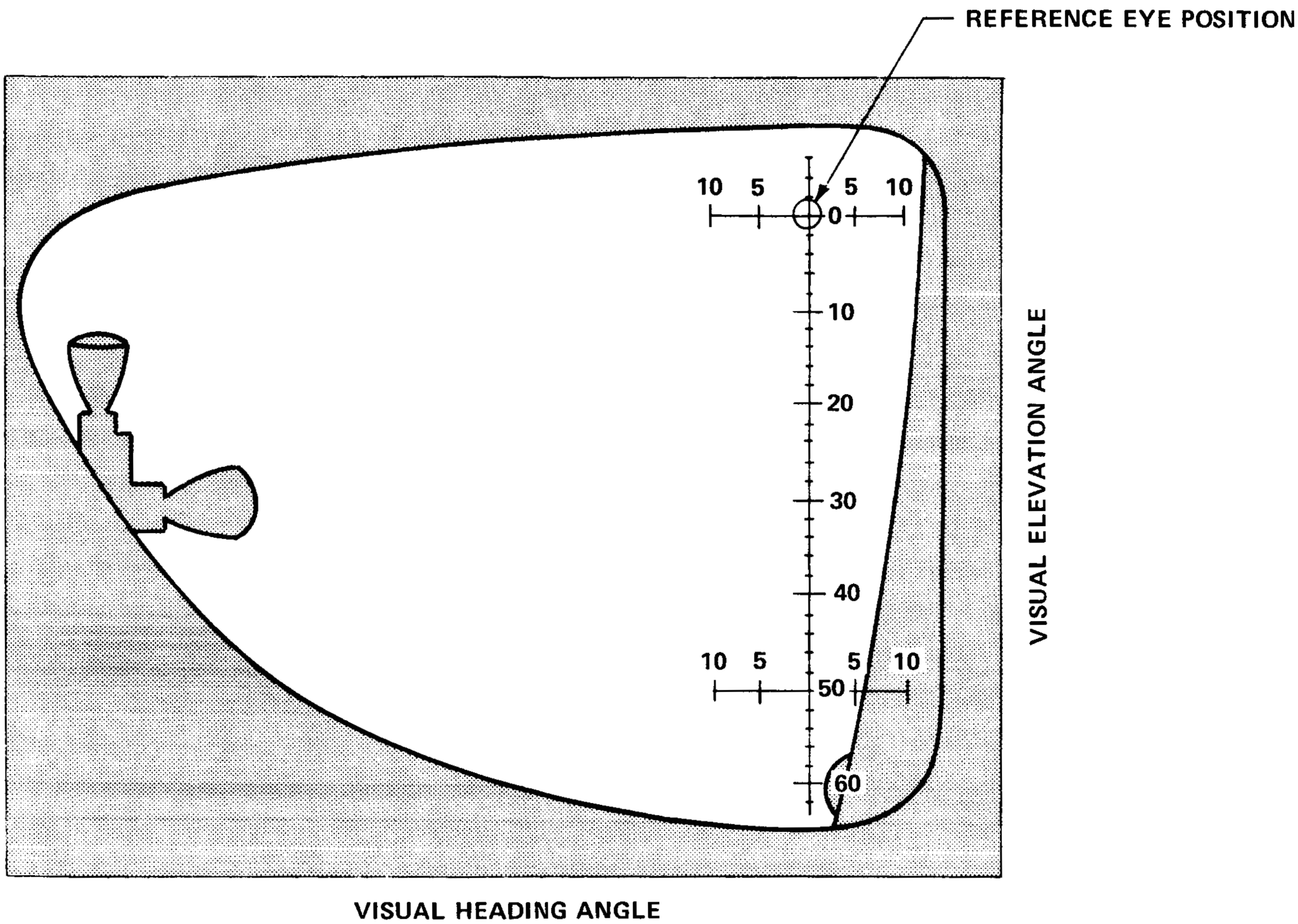

FIGURE 2 – COMMANDER'S VIEWING RESTRICTIONS OUT OF LM WINDOW

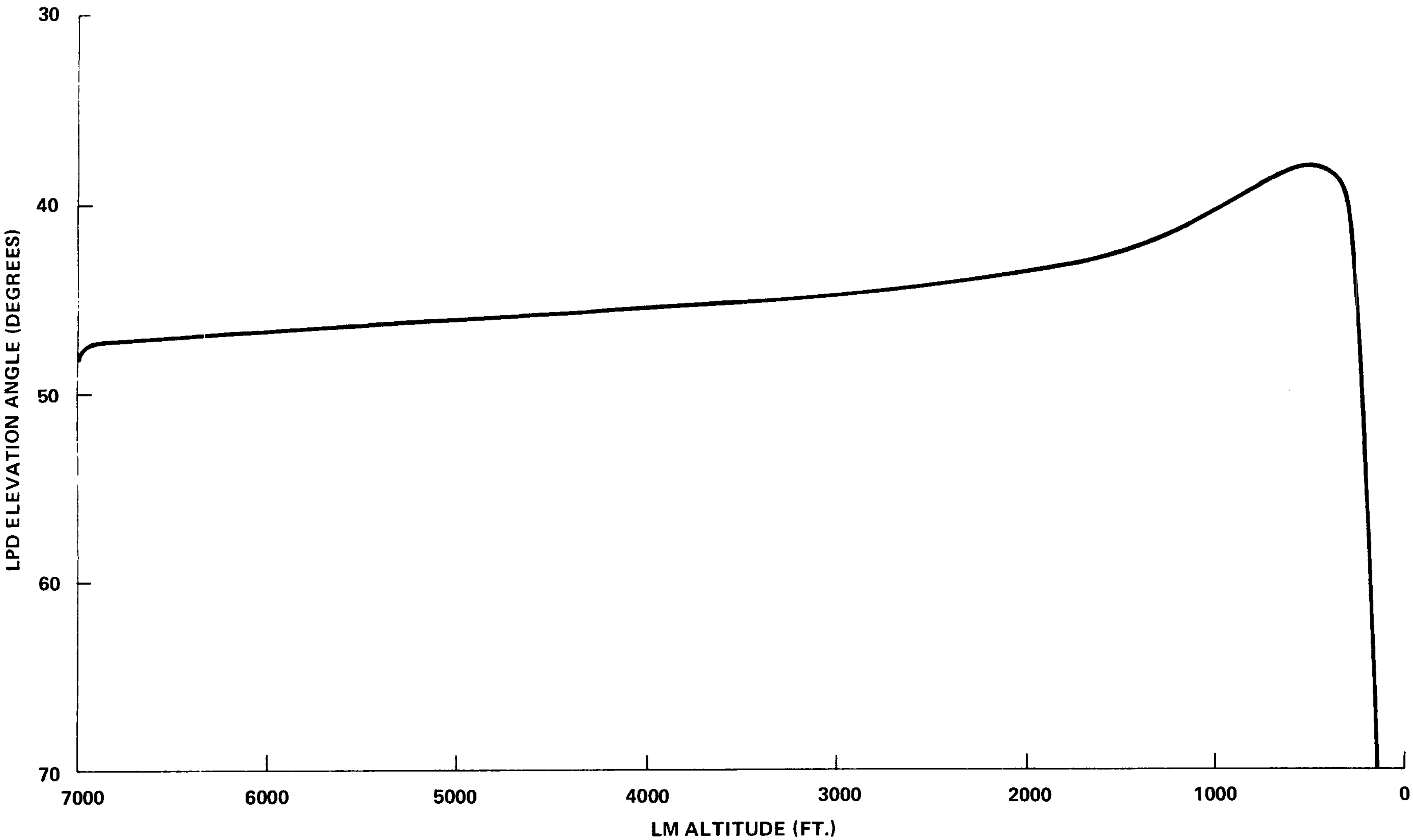

FIGURE 3 – NOMINAL LPD ELEVATION ANGLE TO CURRENT LANDING SITE AS A FUNCTION OF ALTITUDE

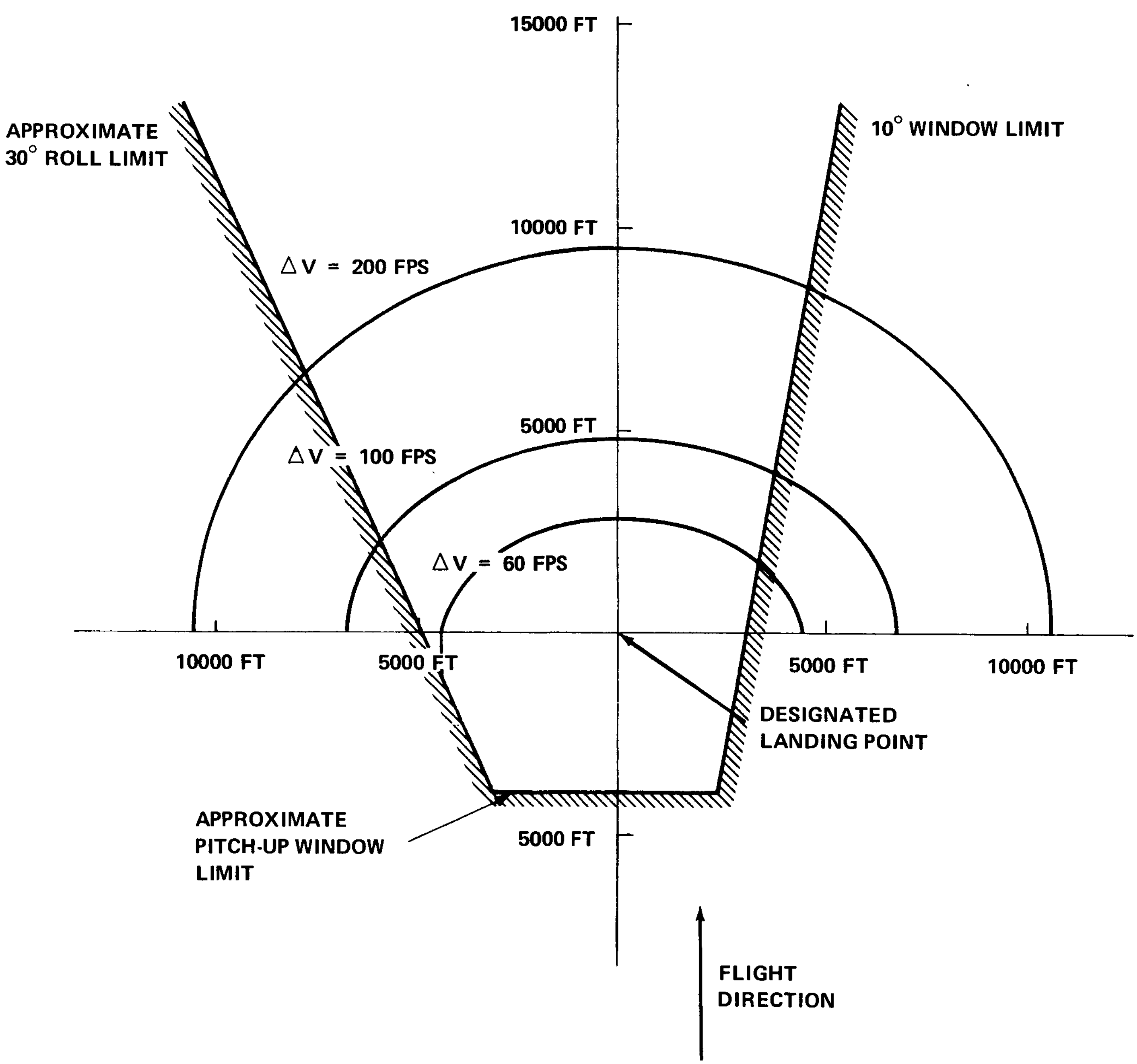

FIGURE 4 – LPD REDESIGNATION CAPABILITY FOOTPRINT AT 5000 FT ALTITUDE

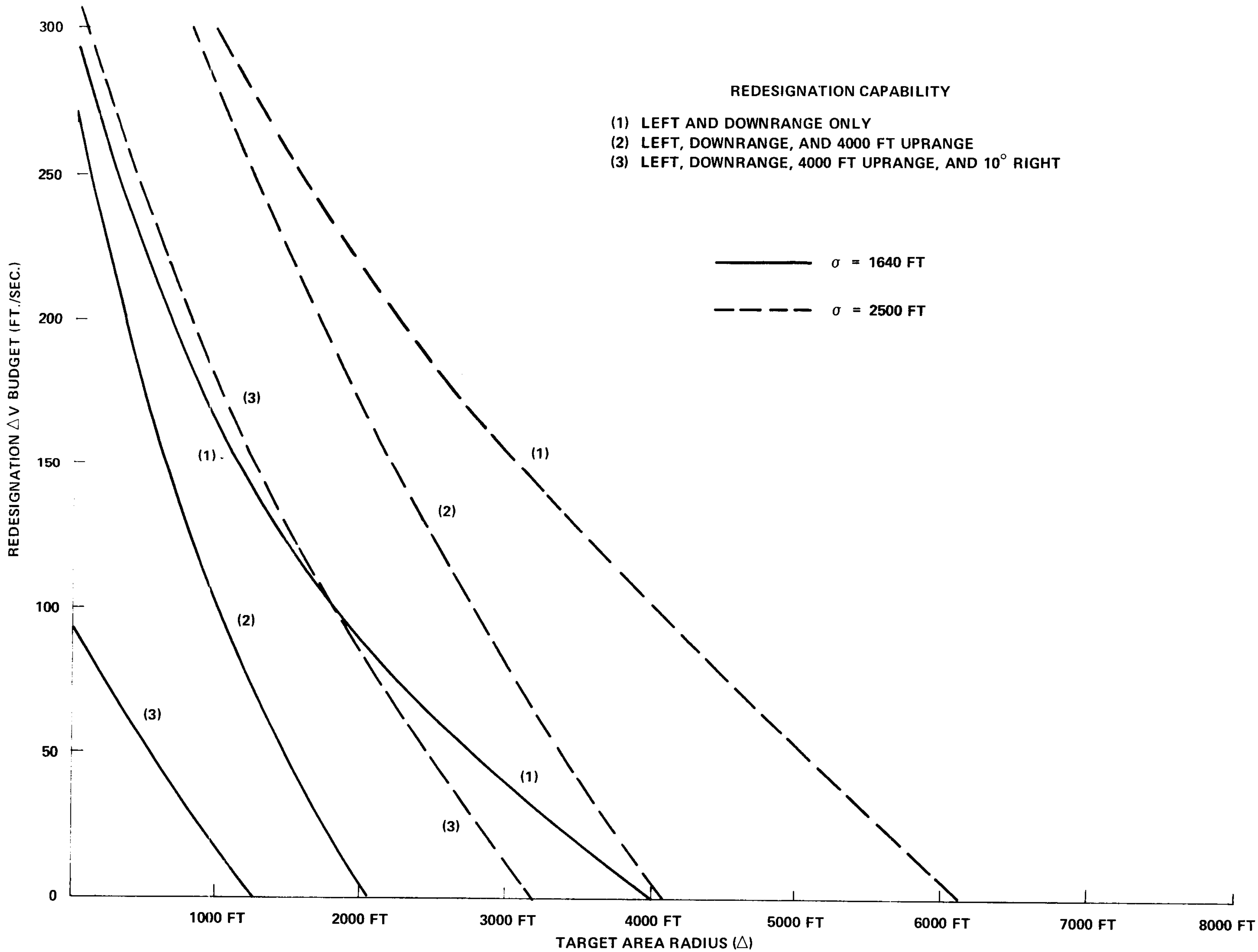

FIGURE 5A – REDESIGNATION ΔV AS A FUNCTION OF Δ FOR 95% PROBABILITY

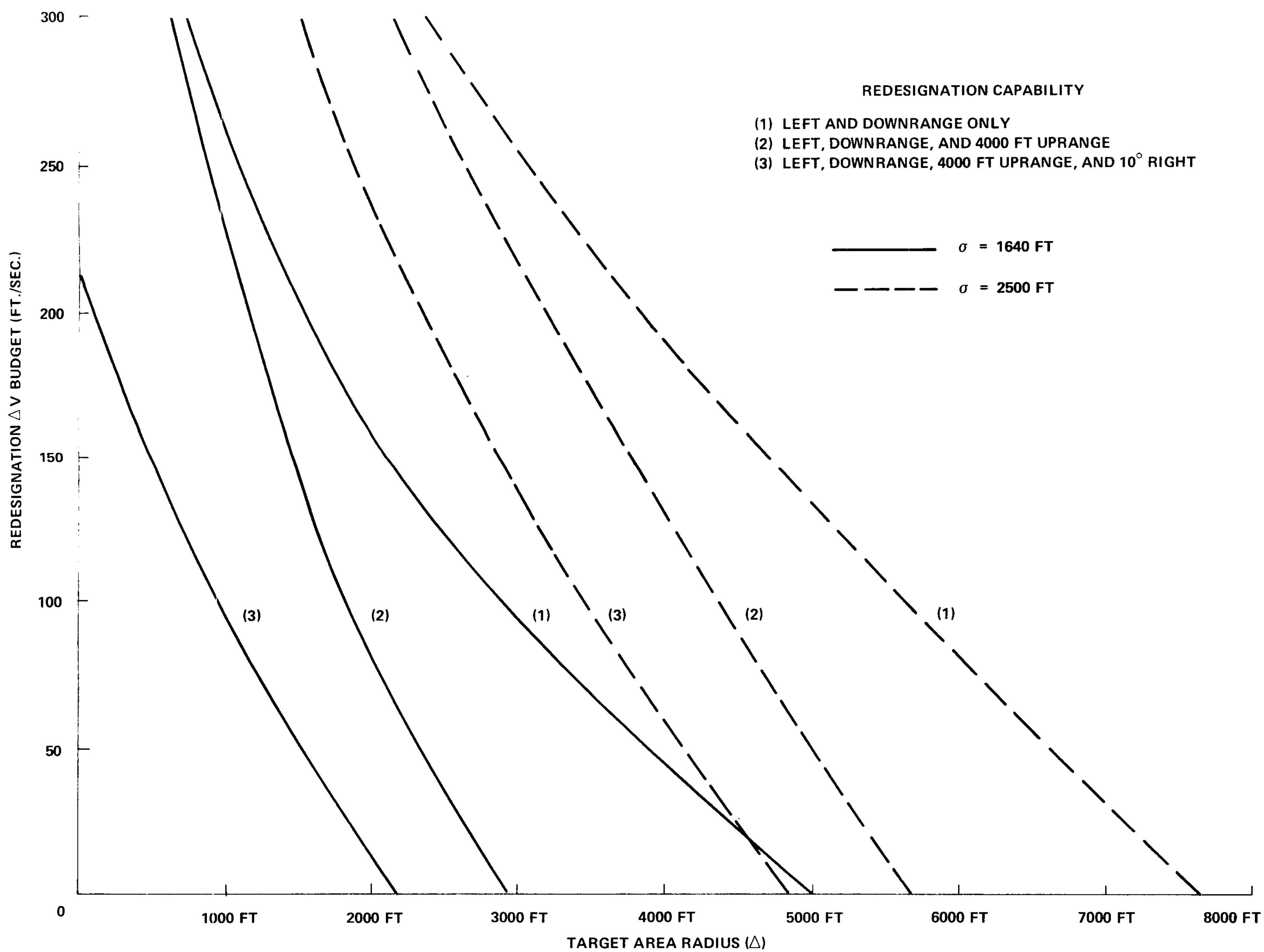

FIGURE 5B – REDESIGNATION ΔV AS A FUNCTION OF Δ FOR 99% PROBABILITY

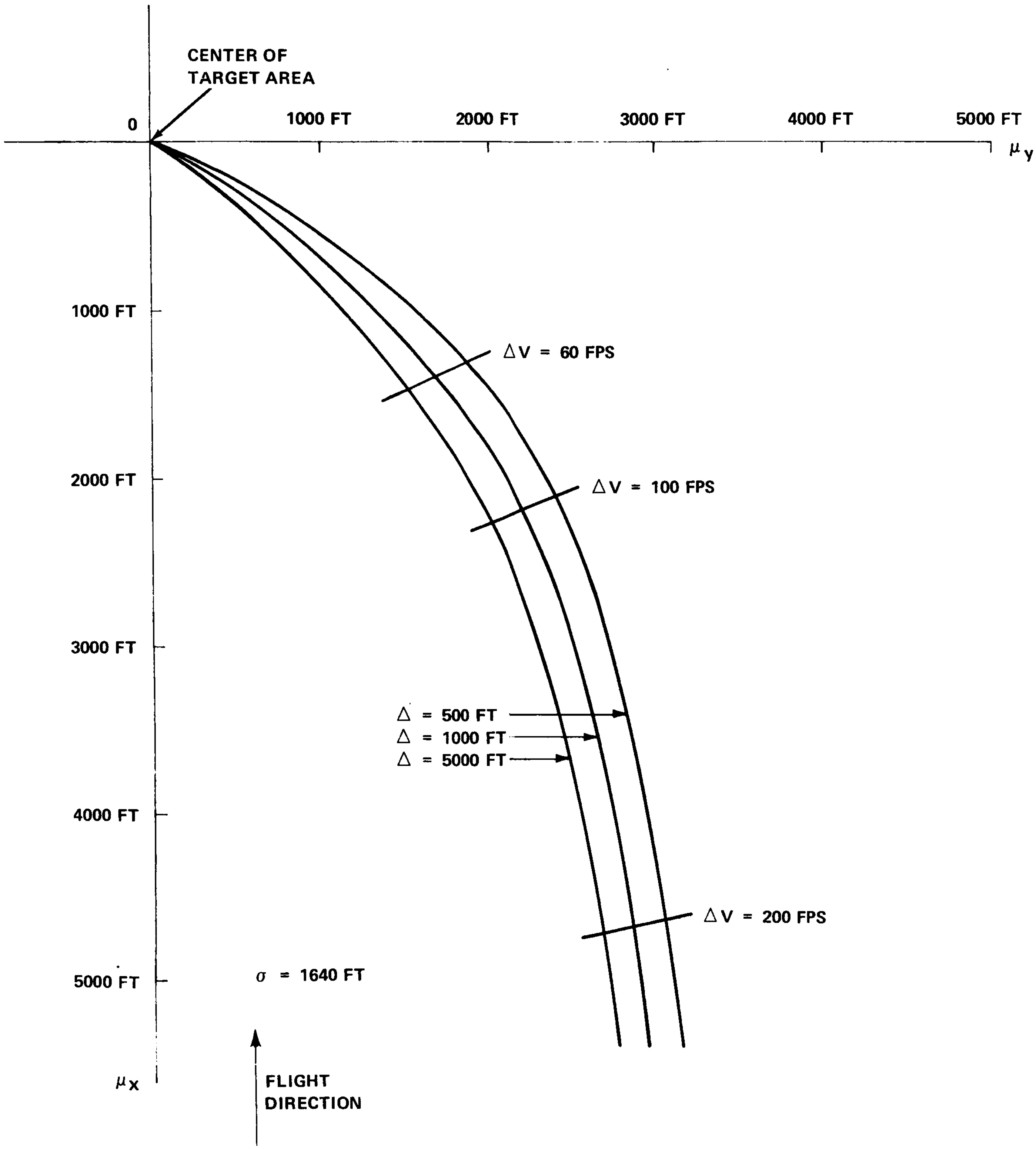

FIGURE 6A – OPTIMUM INITIAL AIM POINT LOCATION FOR LEFT AND DOWNRANGE REDESIGNATION CAPABILITY

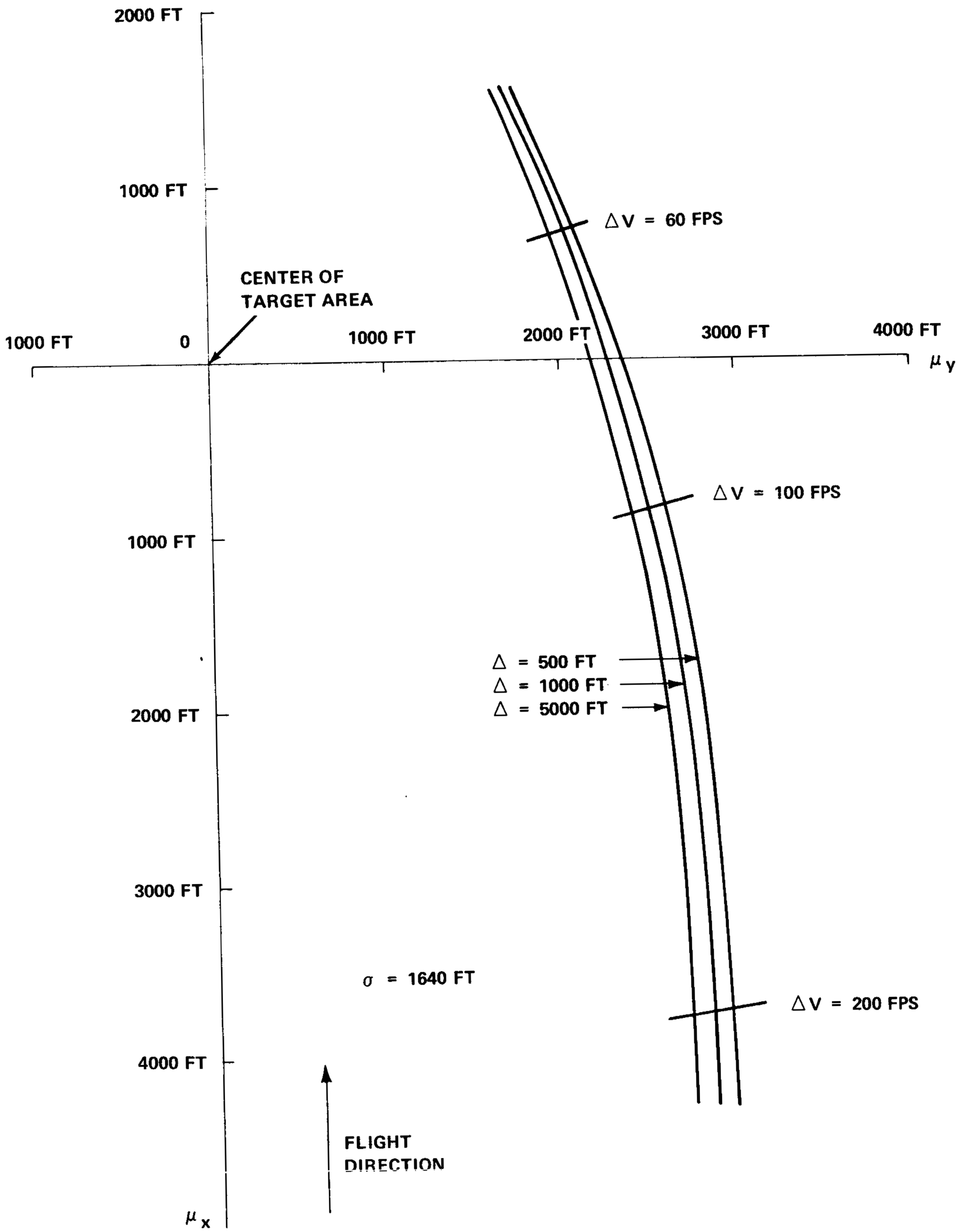

FIGURE 6B – OPTIMUM INITIAL AIM POINT LOCATION FOR LEFT, DOWNRANGE, AND 4000 FT UPRANGE CAPABILITY

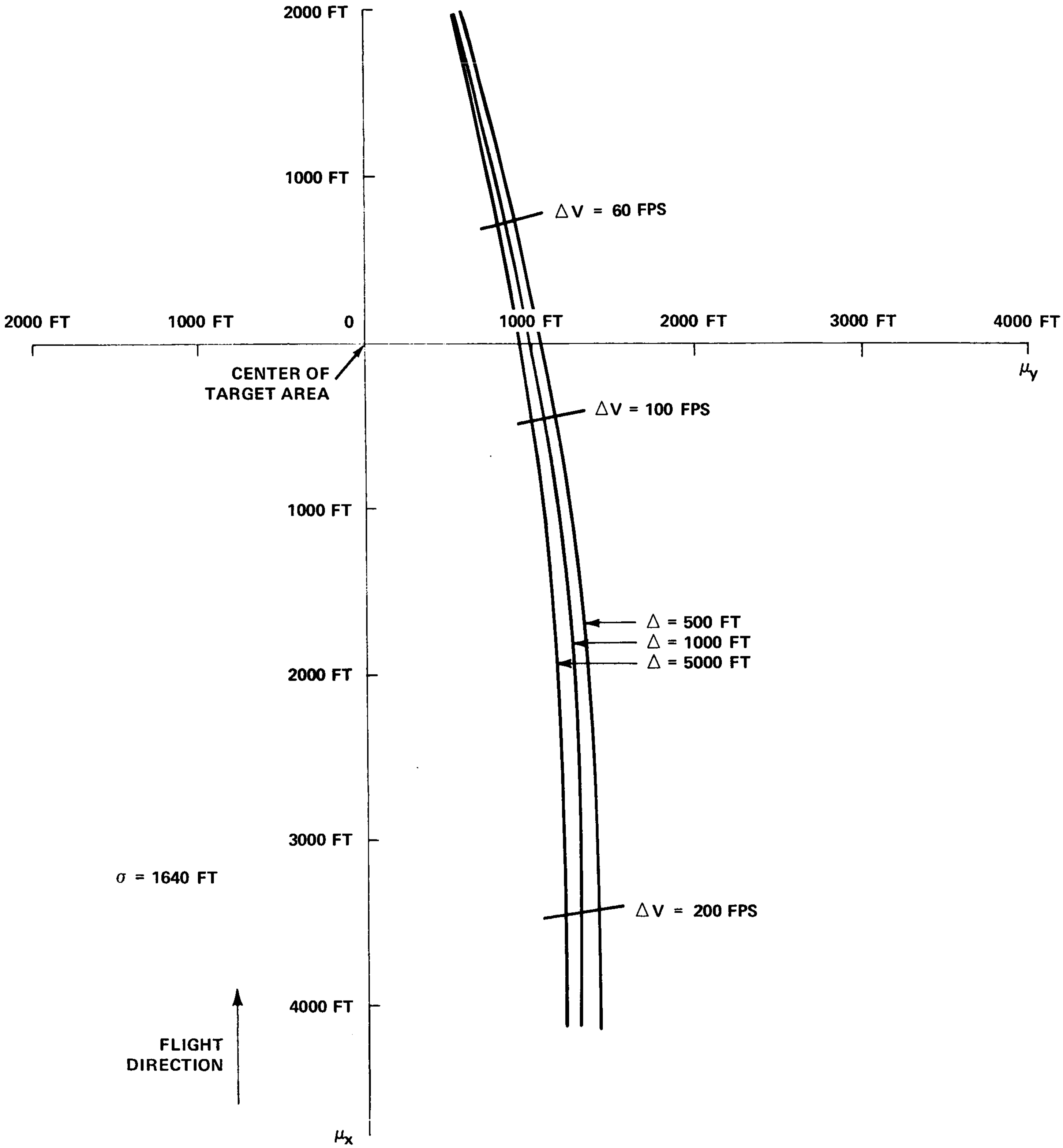

FIGURE 6C – OPTIMUM INITIAL AIM POINT LOCATION FOR LEFT, DOWNRANGE, 4000 FT UPRANGE, AND 10° RIGHT REDESIGNATION CAPABILITY.